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Kao et al.

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(54) **ELECTRICAL MONITORING AND CONTROL SYSTEM**

(75) Inventors: **Imin Kao**, Stonybrook, NY (US); **Brenda Pomerance**, New York, NY (US); **Robert P. Wong**, Huntington, NY (US)

(73) Assignee: **BSafe Electrix, Inc.**

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(51) **Int. Cl.**
G05D 11/00 (2006.01)

(52) **U.S. Cl.** **700/286**; 361/42

(58) **Field of Classification Search** 700/286; 361/42; 324/527

See application file for complete search history.

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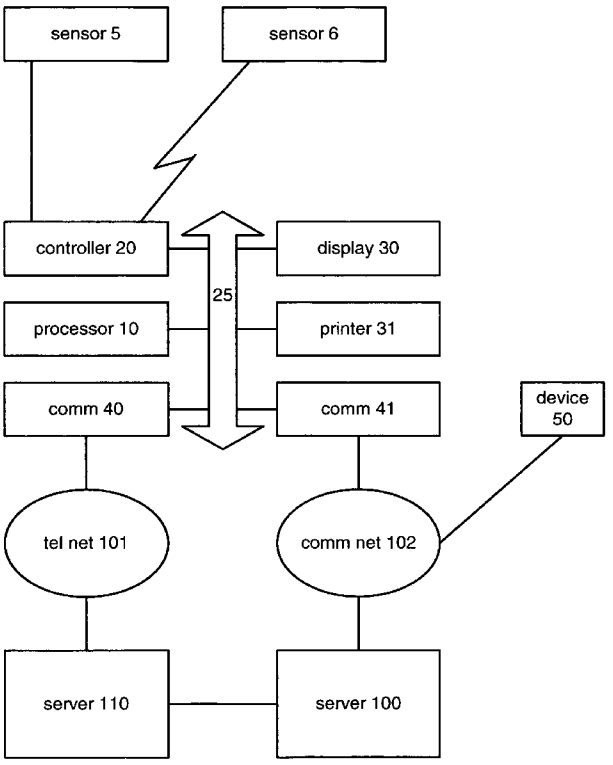
Primary Examiner — Mohammad Ali
Assistant Examiner — Anthony Whittington
(74) *Attorney, Agent, or Firm* — Thomas A. O'Rourke; Bodner & O'Rourke, LLP

(57) **ABSTRACT**

A system for monitoring and controlling the electrical infrastructure of a building includes at least one sensor for sensing an operating characteristic in the building, and a processor for receiving information from the at least one sensor and predicting a future operating characteristic.

24 Claims, 10 Drawing Sheets



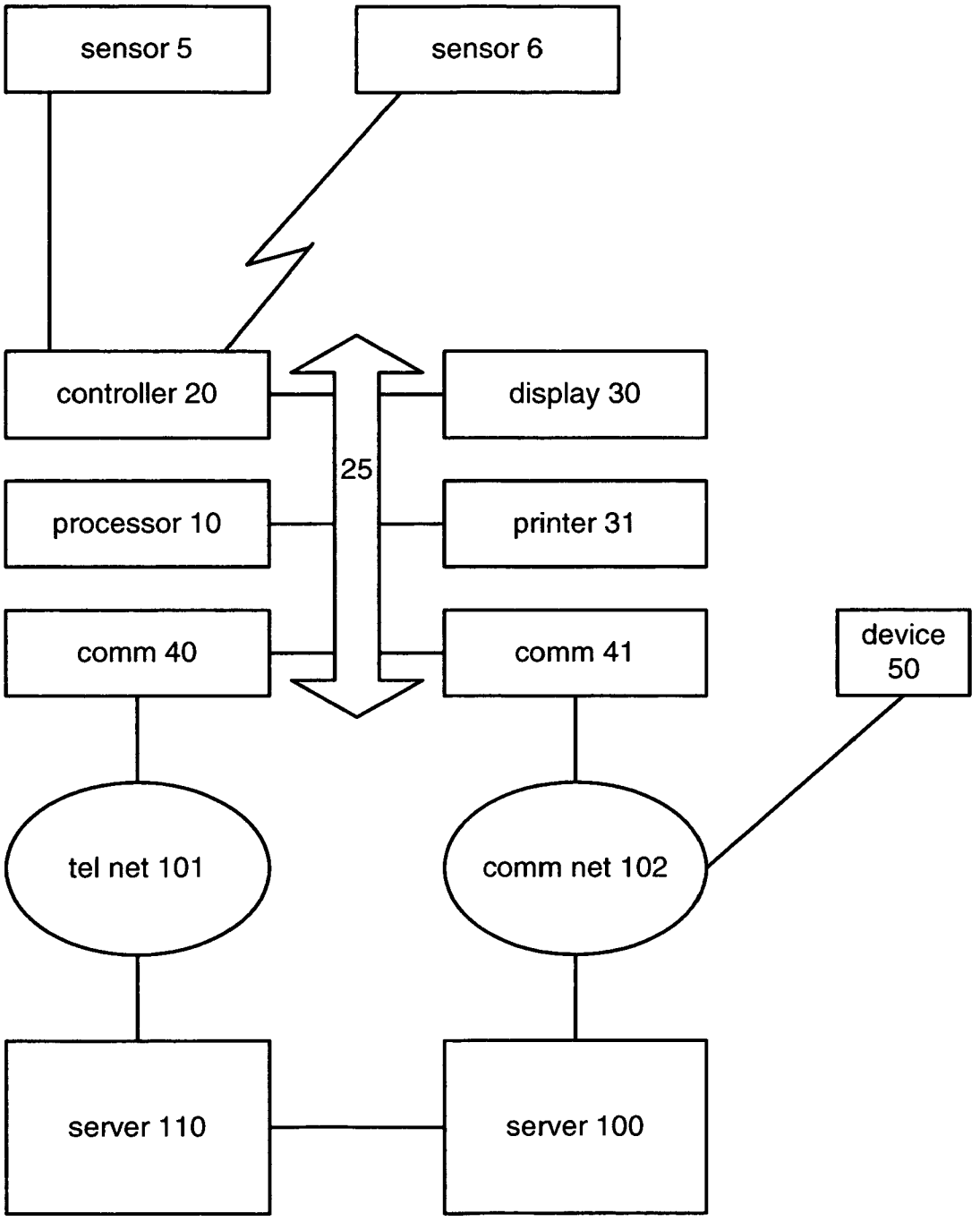

sensor 5
sensor 6
controller 20
display 30
25
processor 10
printer 31
comm 40
comm 41
device 50
tel net 101
comm net 102
server 110
server 100

Fig. 1

Fig. 2

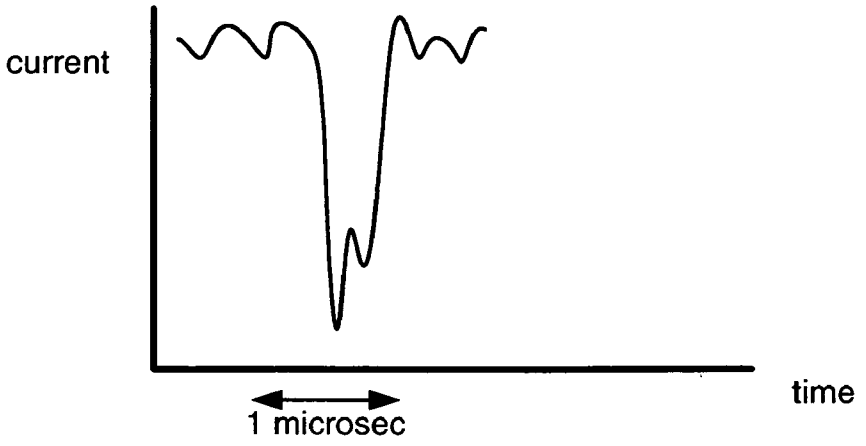


Fig. 3

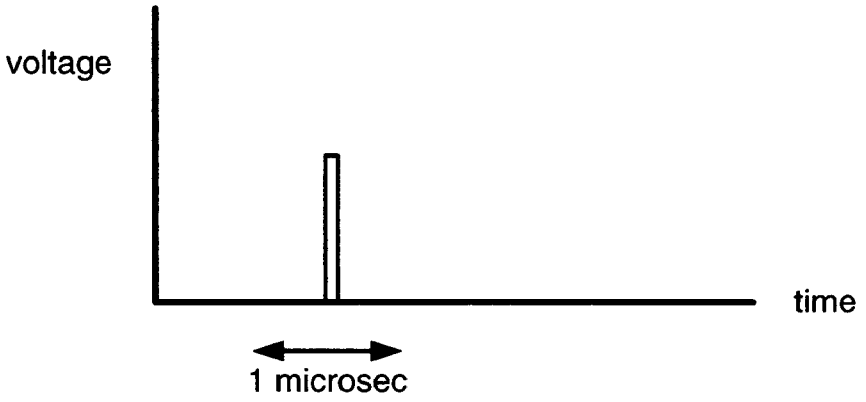


Fig. 4

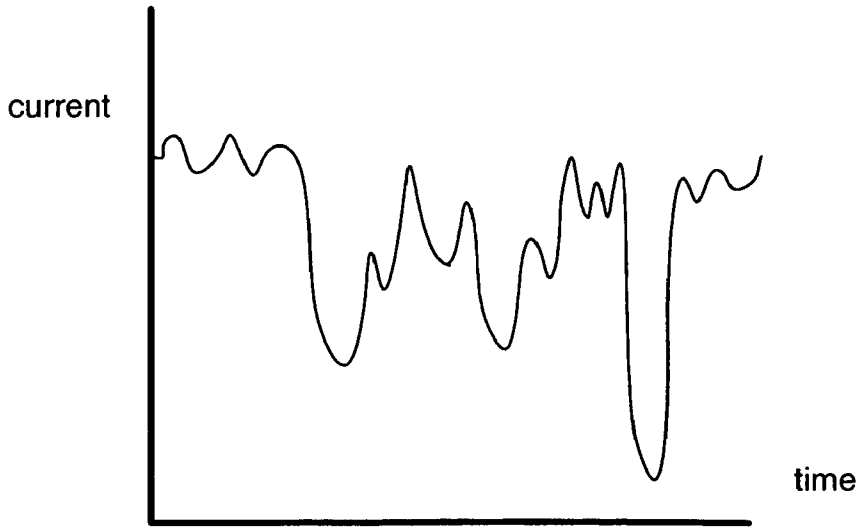


Fig. 5

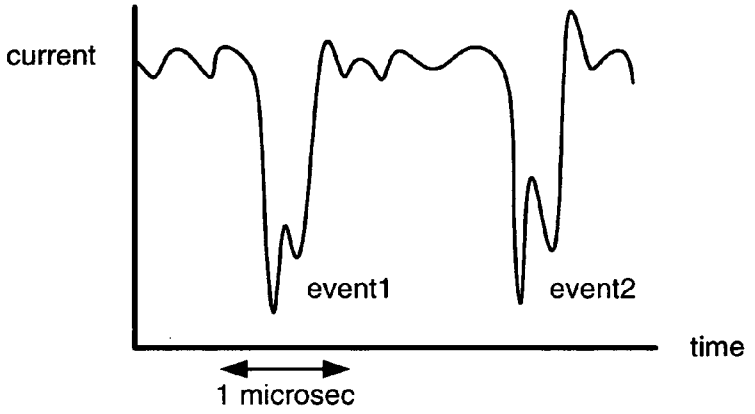


Fig. 6

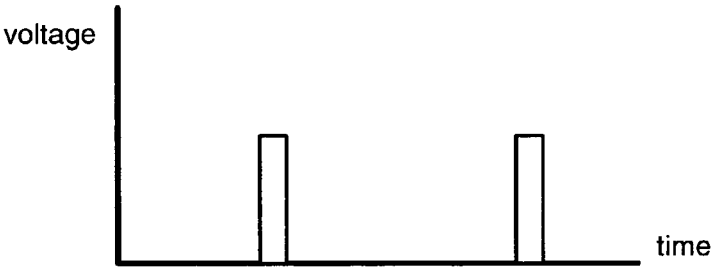
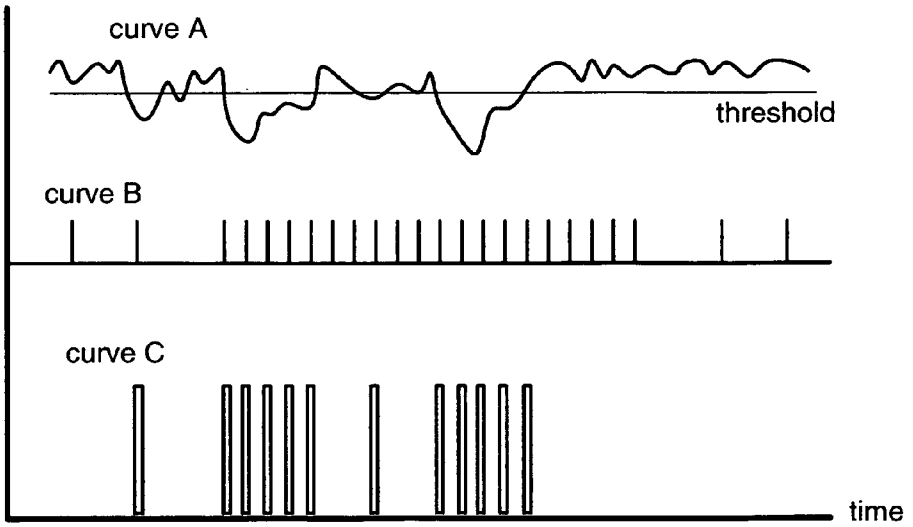
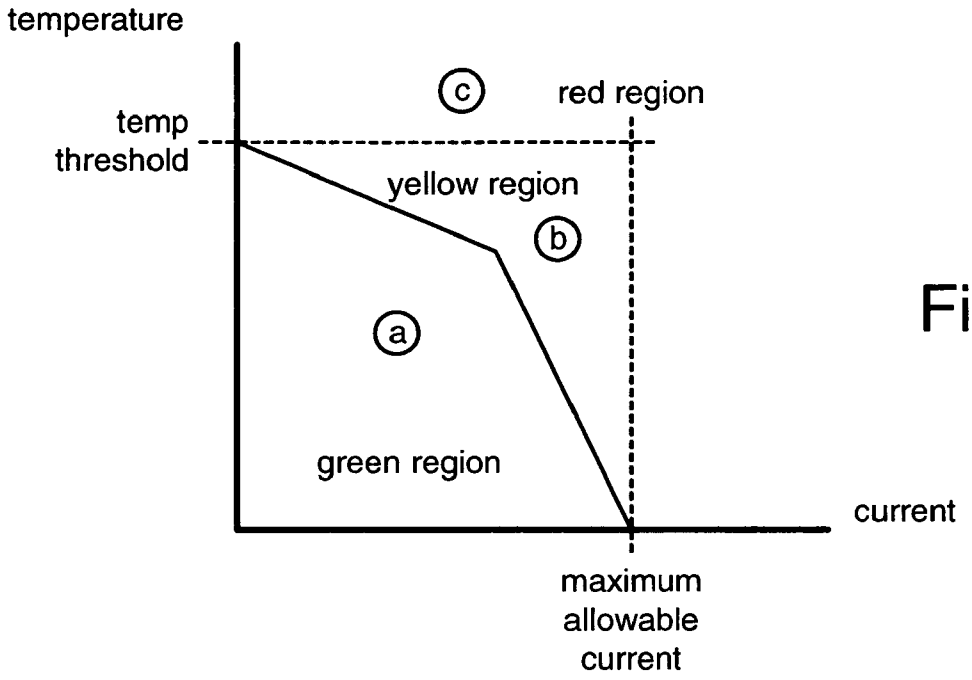


Fig. 7





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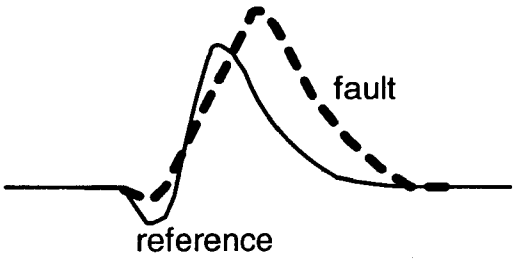

Fig. 9A

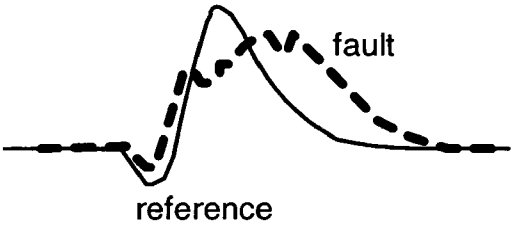

Fig. 9B

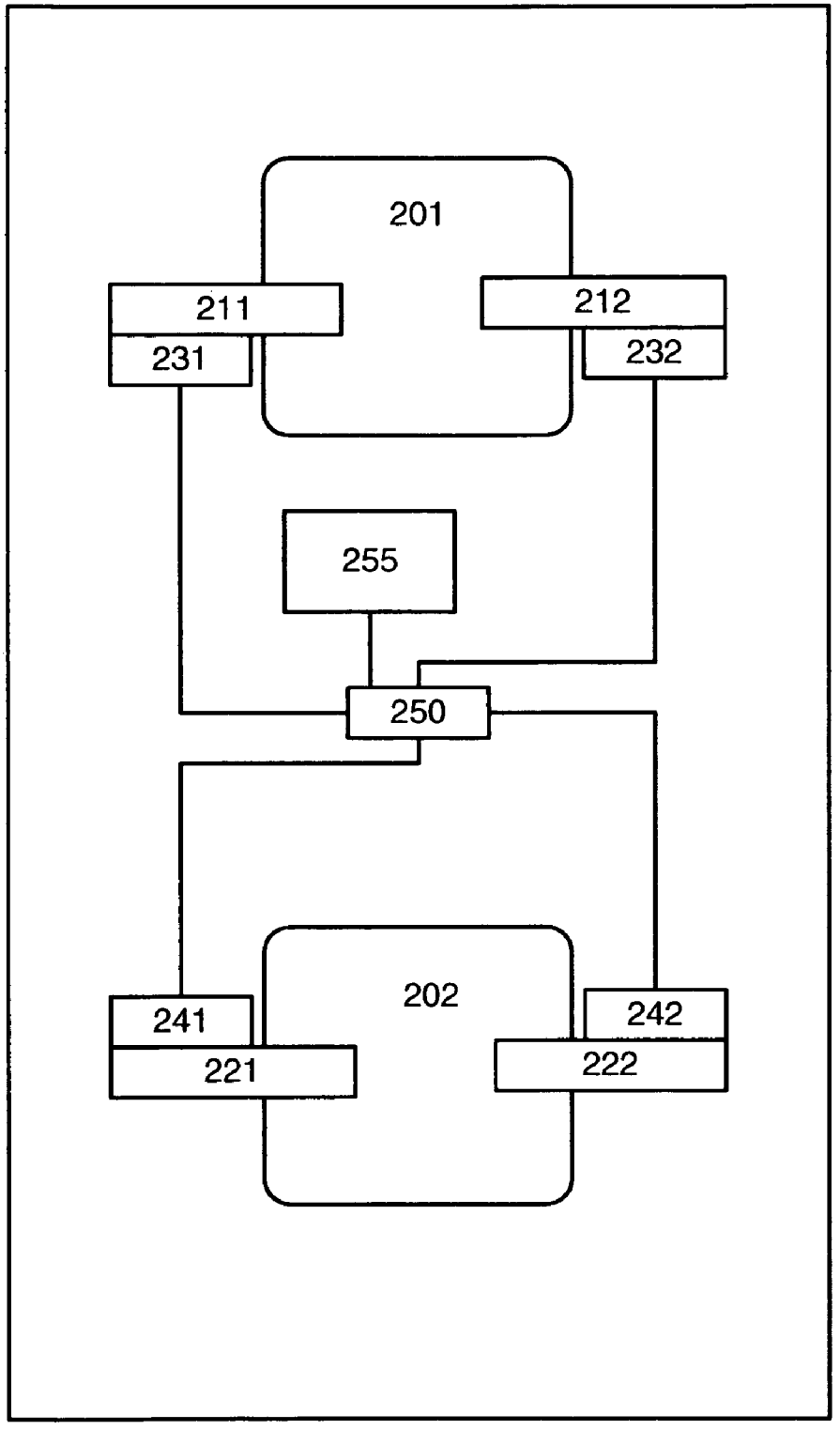

Fig. 10

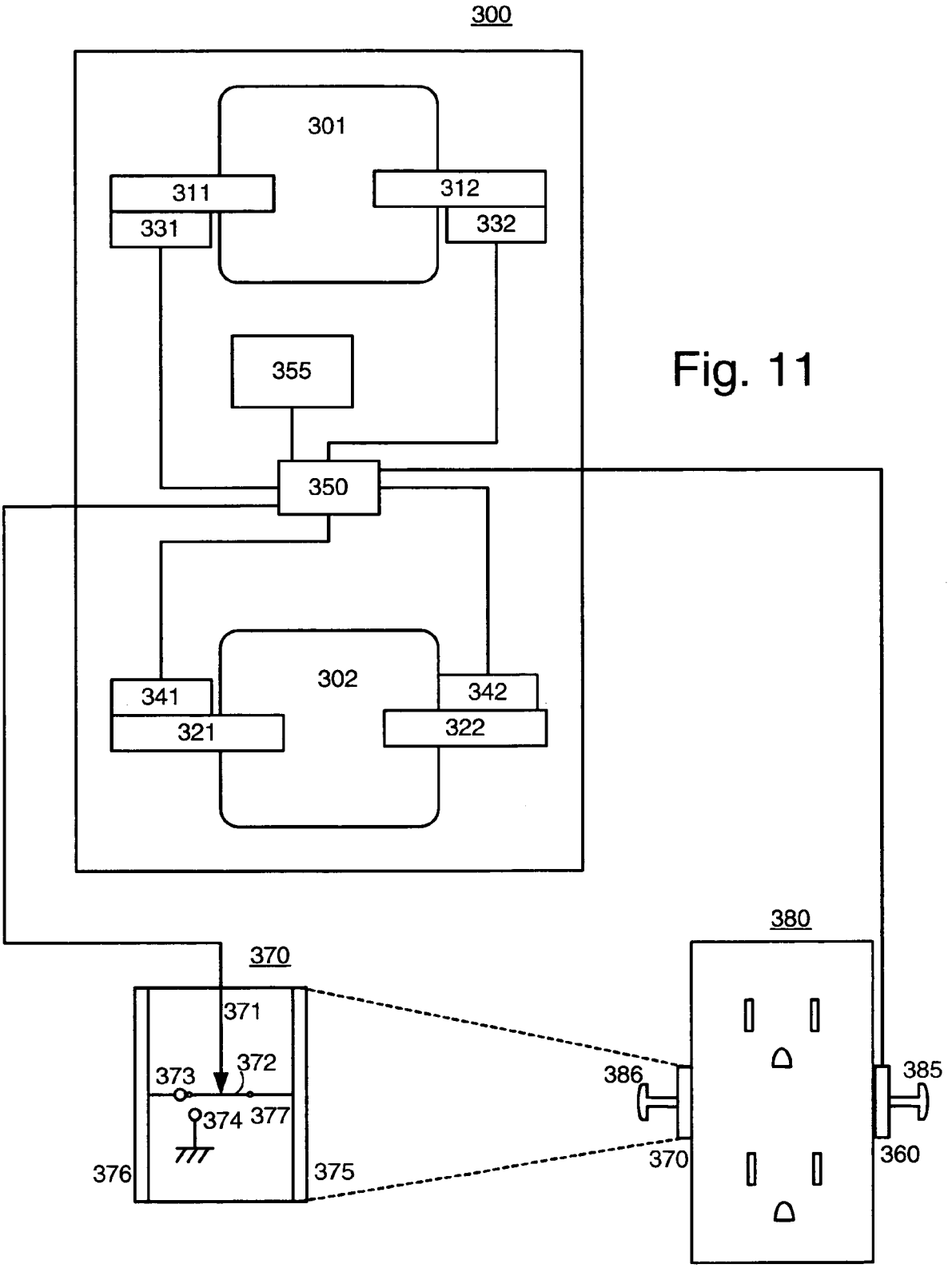
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Fig. 11

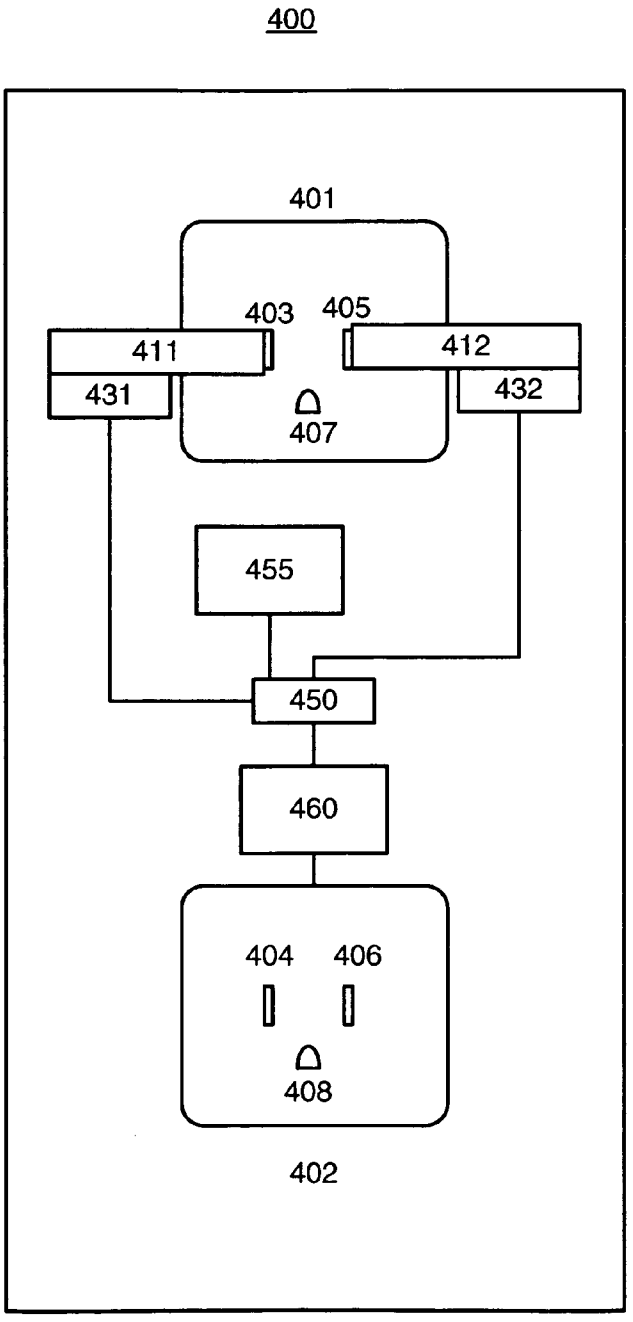


Fig. 12A

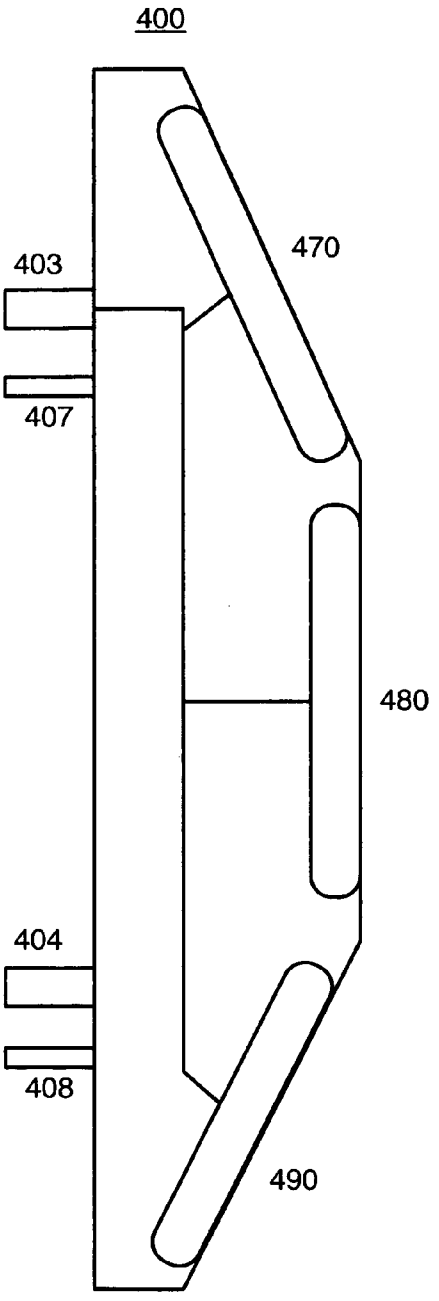
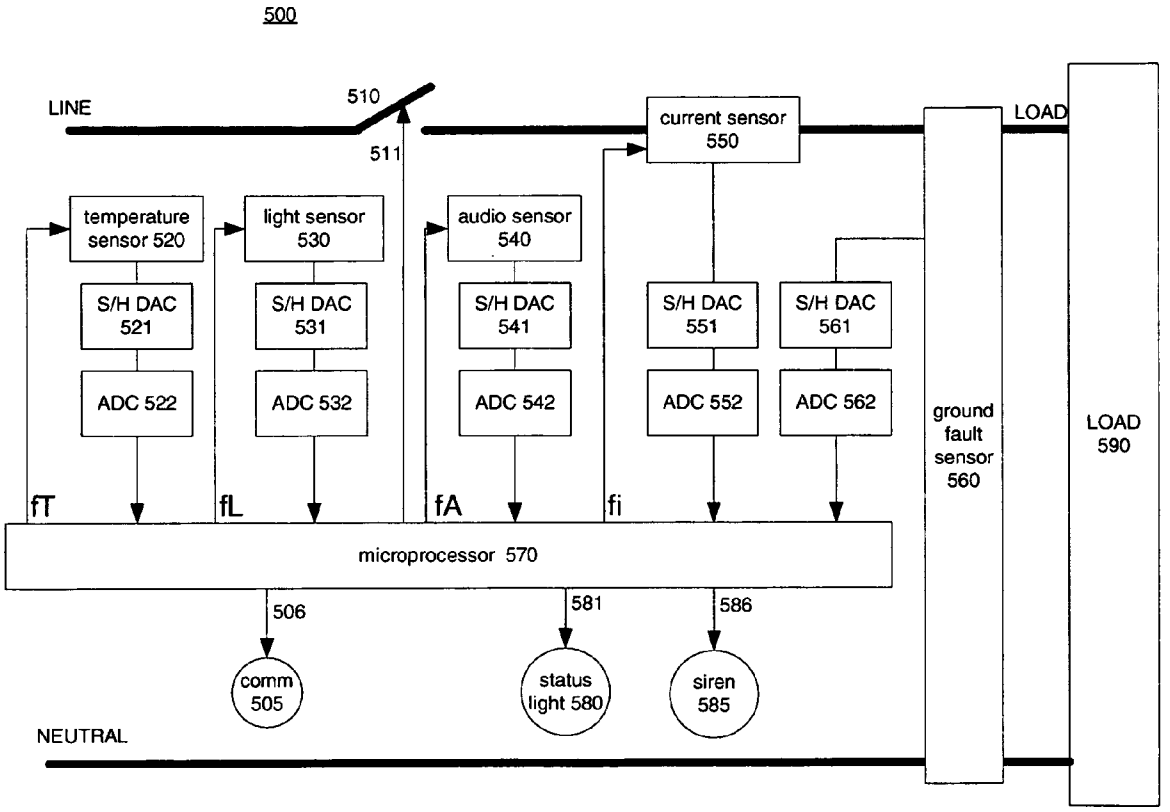


Fig. 12B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LINE
510
511
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LOAD
temperature sensor 520
light sensor 530
audio sensor 540
S/H DAC 521
S/H DAC 531
S/H DAC 541
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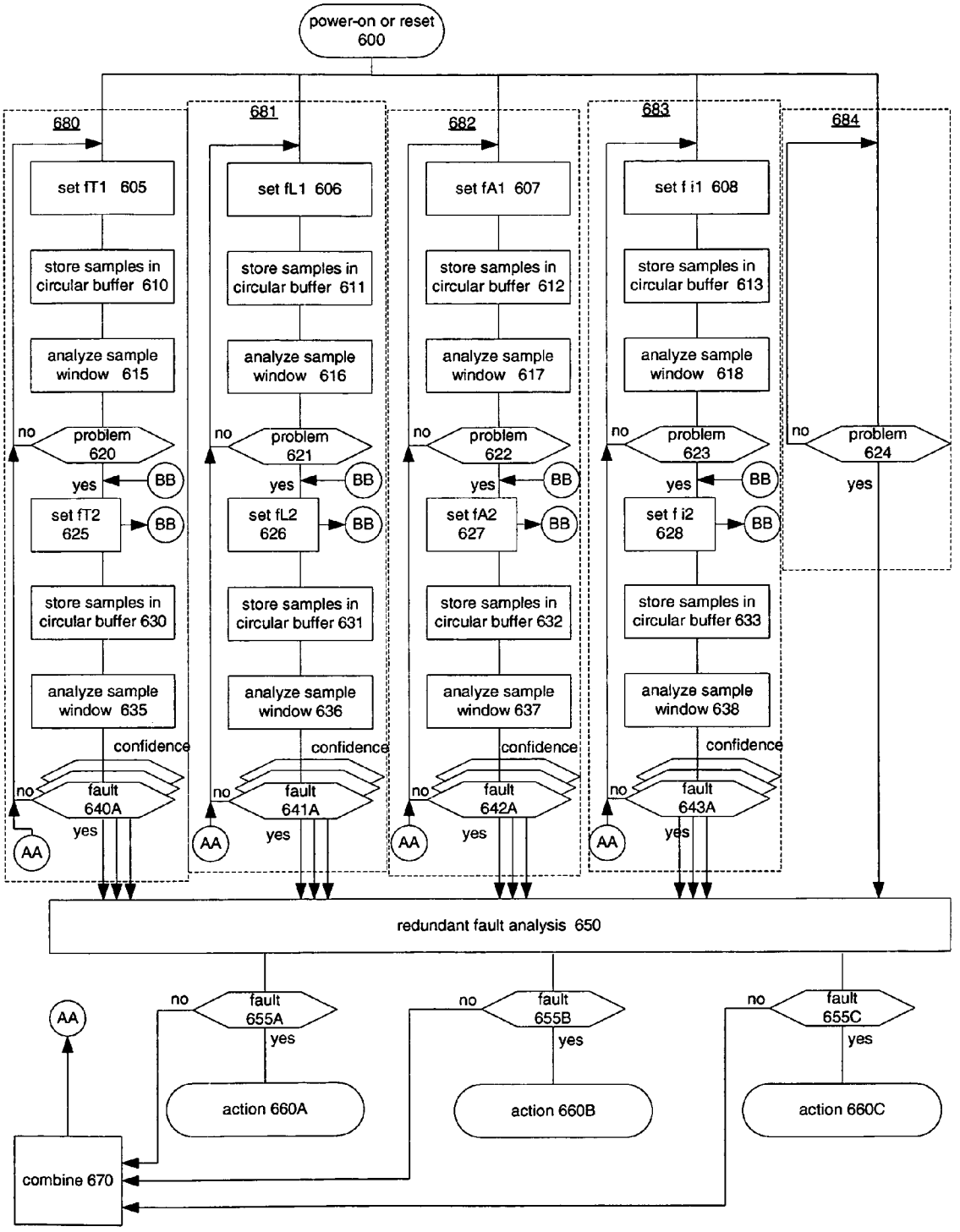
S/H DAC 561
ADC 522
ADC 532
ADC 542
ADC 552
ADC 562
ground fault sensor 560
LOAD 590
fT
fL
fA
fi
microprocessor 570
506
581
586
comm 505
status light 580
siren 585
NEUTRAL

Fig. 13


power-on or reset 600
680
681
682
683
684
set fT1 605
set fL1 606
set fA1 607
set f i1 608
store samples in circular buffer 610
store samples in circular buffer 611
store samples in circular buffer 612
store samples in circular buffer 613
analyze sample window 615
analyze sample window 616
analyze sample window 617
analyze sample window 618
problem 620
problem 621
problem 622
problem 623
problem 624
no
yes
BB
set fT2 625
set fL2 626
set fA2 627
set f i2 628
store samples in circular buffer 630
store samples in circular buffer 631
store samples in circular buffer 632
store samples in circular buffer 633
analyze sample window 635
analyze sample window 636
analyze sample window 637
analyze sample window 638
confidence
fault 640A
fault 641A
fault 642A
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fault 655B
fault 655C
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action 660C
combine 670

Fig. 14

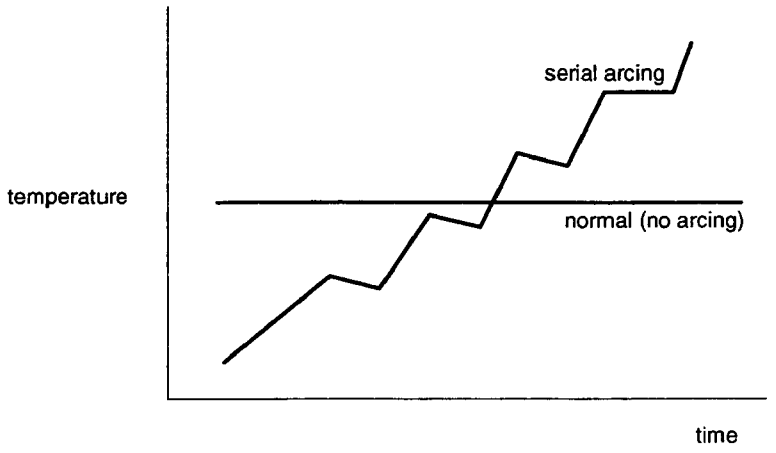

Fig. 15

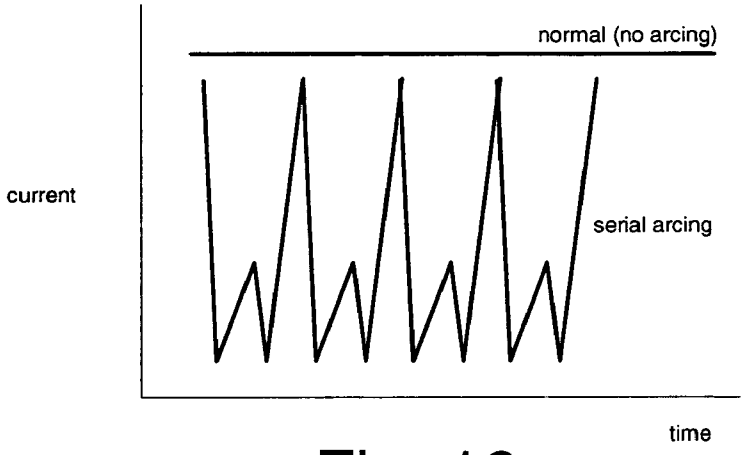

Fig. 16

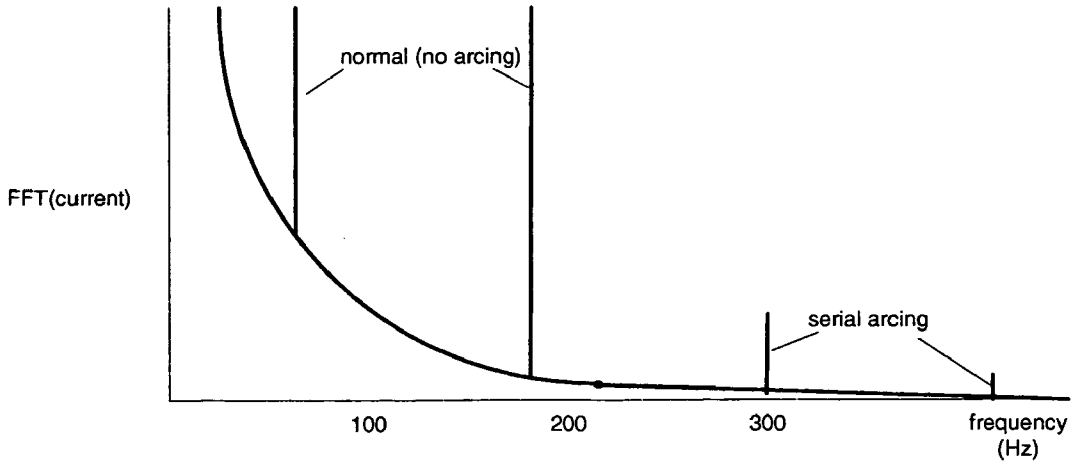

Fig. 17

ELECTRICAL MONITORING AND CONTROL SYSTEM

This application claims priority from U.S. provisional patent application Ser. No. 61/067,693, filed Feb. 29, 2008, having common inventors herewith.

BACKGROUND OF THE INVENTION

The present invention relates to building electrical system monitoring and control.

U.S. Patent Application Publication US 2007/0155349 (Nelson et al.) discloses a system for selectively controlling electrical outlets using power profiling. An electrical outlet includes a socket for receiving a plug, an outlet identification and a signal detector for detecting a signal from the plug, for sending the signal and outlet identification to a controller, and for receiving a command from the controller, such as to reduce or cut power to the device plugged into the outlet when the device's operation deviates from an operational profile for the device. The system may be used with motion sensors and other environmental components.

Blemel and Furse, "Applications of Microsystems and Signal Processing for Wiring Integrity Monitoring", 2001 *IEEE Aerospace Symposium,* 12 pages, the disclosure of which is hereby incorporated by reference, discuss detection and prevention of wiring related problems in aerospace vehicles. Blemel presents a system in which sensors in an aircraft interface with processors; the processors are networked together on an aircraft and are able to communicate with a central web server. The processors implement algorithms for fault detection, identification, location, prediction and messaging.

U.S. Pat. No. 5,991,327 (Kojori) discloses a controller that receives a plurality of sensor readings, including some extra readings for diagnostic protection, and processes the readings to predict and control voltages and currents in an electric arc furnace.

An arc fault circuit interrupter (AFCI) is a circuit breaker designed to prevent fires by detecting non-working electrical arcs and disconnect power before the arc starts a fire. Arc faults in a home are one of the leading causes for household fires. AFCIs resemble a GFCI/RCD (Ground-Fault Circuit Interrupt/Residual-Current Device) in that they both have a test button. GFCIs are designed to protect against electrical shock, while AFCIs are primarily designed to protect against fire.

Starting with the 1999 version of the National Electrical Code (NEC, also called NFPA 70) in the United States, AFCIs are required in all circuits that feed receptacles in bedrooms of dwelling units. This requirement is typically accomplished by using a kind of circuit-breaker (defined by UL 1699) in the breaker panel that provides combined arc-fault and overcurrent protection. Not all U.S.A. jurisdictions have adopted the AFCI requirements of the NEC as written. An AFCI detects sudden bursts of electrical current in milliseconds, long before a standard circuit breaker or fuse would trip.

In 2002, the NEC removed the word "receptacle" leaving "outlets", in effect adding lights within dwelling bedrooms to the requirement. The 2005 code made it more clear that all outlets must be protected. "Outlets" is defined in "Article 100 Definitions" of the NEC as "A point on the wiring system where current is taken to supply utilization equipment" and this includes receptacles, light fixtures, and smoke alarms, among other things.

Beginning January 2008, only "combination type" AFCIs will meet the NEC requirement. The 2008 NEC requires

installation of combination-type AFCIs in all 15 and 20 amp residential circuits with the exception of laundries, kitchens, bathrooms, and garage, and unfinished basements.

Zigbee is a wireless technology that does not have the speed or bandwidth of Wi-Fi or Bluetooth, but is designed for wireless building controls. ZigBee is based on IEEE Standard 802.15.4 and creates a self-organizing wireless network where any ZigBee-compliant device introduced into the environment is automatically incorporated into the network as a node. A number of manufacturers are currently developing devices that incorporate this technology, including switches, thermostats and other common monitoring and control devices. ZigBee devices are battery powered, which means that they do not need any interconnecting wiring. These devices remain dormant until they are activated by an incoming signal, so their batteries can last for months or even years without replacement.

ZigBee devices have the ability to form a mesh network between nodes. Meshing is a type of daisy chaining from one device to another. This technique allows the short range of an individual node to be expanded and multiplied, covering a much larger area. One ZigBee network can contain more than 65,000 nodes (active devices). The network they form in cooperation with each other may take the shape of a star, a branching tree or a net (mesh). There are three categories of ZigBee devices: ZigBee Network Coordinator. Smart node that automatically initiates the formation of the network. ZigBee Router. Another smart node that links groups together and provides multi-hopping for messages. It associates with other routers and end-devices. ZigBee End Devices. Sensors, actuators, monitors, switches, dimmers and other controllers.

Z-Wave is an interoperable standard for residential and light commercial devices, providing reliable, confirmable, low bandwidth, half duplex two way control communications via wireless mesh neworking. The Z-Wave development platform is described at www.zen-sys.com. The Z-Wave Protocol is for communicating short control messages from a control unit to one or more slave units. Slave units can forward commands to other slave units. The ZM3102N Z-Wave Module contains the ZW0301 Z-Wave Single Chip, system crystal and RF front-end circuitry. The ZW0301 Single Chip includes an RF transceiver, 8051 MCU core, SRAM, Flash Memory for Z-Wave Protocol and OEM Application storage software, Triac Controller, and various hardware interfaces.

Motorola sells Home Monitoring and Control System Wireless Temperature Sensors, namely model HMTS1050 and model HMSM4150, that are intended to be placed in a room, and programmed with an upper and/or lower limit. When the limit is exceeded, the system sends a text alert to a cell phone or e-mail.

While there is concern about the electrical infrastructure of buildings, including residential and commercial, there is still room for improvement.

SUMMARY OF THE INVENTION

In accordance with an aspect of this invention, there is provided a system for monitoring and controlling the electrical infrastructure of a building.

It is not intended that the invention be summarized here in its entirety. Rather, further features, aspects and advantages of the invention are set forth in or are apparent from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing the elements of the present system;

FIG. **2** is a chart showing instantaneous arcing;

FIG. **3** is a chart showing how a digital optical sensor reacts to the signal of FIG. **2**;

FIG. **4** is a chart showing continuous arcing;

FIG. **5** is a chart showing two instances of single arcing;

FIG. **6** is a chart showing how a digital optical sensor reacts to the signal of FIG. **5**;

FIG. **7** is a chart showing, as "curveA", the current versus time for an intermittent contact; as "curveB", a sampling rate that is dynamically changed; and as "curveC", the output of a sensor whose sampling rate is dynamically changed;

FIG. **8** shows a vectorized map;

FIGS. **9**A and **9**B are curves referenced in explaining iFDD;

FIG. **10** is a block diagram showing a faceplate for sensing operation of a device plugged into an outlet;

FIG. **11** is a block diagram showing a faceplate for sensing operation of a device plugged into an outlet, and for terminating power when an exception condition occurs;

FIGS. **12**A and **12**B are block diagrams showing a back view and a side view of a current tap for sensing operation of device plugged into it;

FIG. **13** is a schematic of a circuit according to the present invention;

FIG. **14** is a flowchart for the circuit of FIG. **13**;

FIG. **15** shows temperature vs. time curves for normal operation and serial arcing;

FIG. **16** shows current vs. time curves for normal operation and serial arcing; and

FIG. **17** shows FFT frequency spectra for normal operation and serial arcing.

DETAILED DESCRIPTION

FIG. **1** shows sensors **5**, **6** coupled to controller **20**. Sensor **5** uses a wireline connection, while sensor **6** uses a wireless connection. Local communication network **25** couples processor **10**, controller **20**, display **30**, printer **31**, and communication interfaces **40**, **41**. Each of processor **10**, controller **20** and communication interfaces **40**, **41** may be one or more general purpose computers programmed according to the present invention.

Communications interface **40** is coupled via suitable means, such as a wireline or wireless connection, to public switched telephone network **101**, which in turn is coupled to third party server **110**. The third party may be, e.g., a police station, firehouse, or other service.

Communications interface **41** is coupled via suitable means, such as a wireline or wireless connection, to communications network **102**, such as the Internet, which is also coupled to server **100** and device **50**. Server **110** is coupled to server **100**, such as directly or via communication network **102**.

Sensor **5** senses the operating condition of one or more components, such as a wall receptacle, a plug-in group of receptacles (also referred to as a current tap or power strip), a wall on/off switch, a wall dimmer, a fusebox, power-carrying wires, communications wires and so on. The operating condition includes environmental conditions such as temperature, humidity and so on. The sensing occurs in a manner suitable for the device, and may include temperature readings, voltage readings, power readings, image readings, acoustic readings and so on. In the case of communication lines, sensing may include the name and identity of a device, such as its Internet Protocol (IP) address, and other network monitoring functions. The sensing may occur in a passive or an active mode. Sensor **6** is generally similar to sensor **5**, but senses other devices, demonstrating that there are plural sensors in the present configuration.

For a new installation, sensors **5**, **6** may be built-in, and their location optimized according to a procedure. For an existing installation, sensors **5**, **6** can be retrofit via plug-in or stick-on modules designed to minimize installation difficulty.

Sensor **5** may be similar to Tmote Invent, a fully packaged wireless sensing unit built on Moteiv's Tmote Sky wireless module, the follow-on to Moteiv's Telos sensor. Moteiv was purchased by Sentilla, and the Tmote Invent is no longer offered. Tmote Invent, designed for industrial applications including building monitoring and security control, included integrated sensors for light, temperature, vibration (2-axis accelerometer) and sound (microphone). Tmote Invent included a speaker for auditory feedback, headphone jack for discrete applications, and LEDs for visual feedback. Included with each Tmote Invent Application Kit was Moteiv's robust distribution of the TinyOS open-source operating system. Designed for low-power, long-lived mesh networking, the distribution allows application developers to tune and configure the system through highly flexible interfaces. The result was a customizable yet robust low-power sensing system. Features included: Low power wireless mesh technology, Programming and data collection via USB, Light, Temperature, Acceleration, and Sound sensors, Speaker, LEDs, and User input buttons, rechargeable battery that charges through any standard USB port, 250 kbps 2.4 GHz IEEE 802.15.4 Chipcon Wireless Transceiver, Interoperability with other IEEE 802.15.4 devices, 8 MHz Texas Instruments MSP430 microcontroller (10 k RAM, 48 k Flash), Integrated antenna with 50 m range indoors/125 m range outdoors, Ultra low power consumption.

Sensor **5** is associated with one of a variety of devices (not shown), such as an electrical receptacle, a faceplate, a circuit breaker, an air-conditioning unit, a refrigerator, and so on. Sensor **5** may have local data analysis capability.

Multiple characteristics of the same device or line may be sensed, to provide a variety of readings, possibly redundant, discussed below.

Controller **20** receives the sensor readings and stores them in a storage device (not shown). In cooperation with processor **10**, controller **20** processes the sensor readings.

For example, controller **20** may determine if a sensor reading is outside of a range, and then alert processor **10** that emergency processing is needed. If the sensor reading is within the range, then controller **20** simply stores the reading so that processor **10** will process it in due course.

Processor **10** processes sensor readings to predict faults and to detect faults. Processor **10** reports status of the devices and wires being monitored to display **30**, printer **31**, and possibly other notification devices such as an audible alarm. In some cases, processor **10** takes control action on its own, such as isolating failed devices by eliminating power. In other cases, processor **10** responds to instructions entered locally by an input device (not shown), or received from a remote controlling unit, such as server **100** or **110**.

Processor **10** may also communicate with conventional monitoring systems, such as home security systems via an interface (not shown).

Processor **10** also reports status to server **100** and server **110**.

Server **100** and server **110** can query processor **10** for status. For example, if sensor **5** is a camera, then server **100** can command processor **10** to obtain an image from sensor **5**.

Server **100** functions in similar manner as processor **10**, except server **100** can run more sophisticated software, and can combine readings from a wider variety of sensors and

systems. For example, server **100** may run image processing software that is beyond the processing capability of processor **10**.

Server **100** can poll processor **10** for its status, and receive messages from processor **10**, either periodically or in response to events. Server **100** can download updates to processor **10**.

Since server **100** communicates with many systems, it serves as a one-stop point of contact for a user, such as a homeowner away from home. The user can communicate with server **100** via device **50**, which may be a personal computer, cellphone with Internet browsing capability, vehicle telephone, or other suitable device. Server **100** may communicate alerts or other status information to device **50**.

For example, a third party server (not shown) may be a child location tracking service, and the user can readily determine, via device **50**, whether the child is near a failed receptacle.

Energy conservation procedures are implemented when the sensed information is used to control the devices being sensed.

In a fault detection and diagnosis (FDD) process, sensor readings are obtained and analyzed to detect and/or predict faults. A "fault" refers to any operation outside a "normal" operating range, that is, cessation of operations is not necessarily needed to be in a fault condition. For example, an electrical outlet with serial arcing is likely to exhibit fault characteristics. As another example, excessive energy use by a device may be considered a fault, and the device can be automatically controlled to reduce its energy usage.

Sampling sensors at a low rate may miss events such as transients occurring between sampling points. However, generally, it is not practical to continuously sample many sensors at a high sampling rate, because (i) a large amount of data will need to be transmitted, (ii) when comparing data from different sensors, synchronization becomes difficult with huge volumes of data, and (iii) storage limitations make it costly to save huge amounts of data; typically only a predefined amount of data is saved which limits historical analysis to only the timeframe of predetermined amount of data.

An event-triggered sampling rate is determined as follows. A first sensor is sampled at a higher data rate than other sensors. The sensor readings from all sensors are analyzed, and when first event conditions are met, the sampling rate of other sensors is adjusted, the adjustment occurring during a predetermined time interval or until second event conditions are met.

Event-triggered sampling relies on bi-directional communication. Generally, sensor readings are sent from sensor **5** to controller **20**, and control information is sent from controller **20** to sensor **5**.

Sensors can include current sensors (for example, Hall-effect sensors), temperature sensors such as a thermocouple, humidity sensors, optical sensors, spatial thermal imaging sensors (infrared cameras), other regional sensors, and so on. Sensors can be analog or digital.

In one embodiment, the first and second event conditions are predefined, such as by a person. Predefined event conditions exhibiting a certain pattern over an approximate time interval are sometimes referred to as a fingerprint or profile. Analysis is typically called fingerprint analysis with pattern recognition.

For example, when a device is plugged into a receptacle, there may be an immediate burst of current activity, possibly corresponding to sparks on the blades of the plug; this corresponds to a first fingerprint. As another example, a device that is plugged into a receptacle and changed from an "off" to an "on" condition exhibits a particular pattern of current activity, corresponding to a second fingerprint.

The analysis software determines whether a normal event is occurring by comparing the duration of activity with the duration of the known fingerprints; if the duration is outside the fingerprint time bounds, then an abnormal event is occurring and a fault is likely.

The analysis software is further able to determine whether a normal event is occurring in a normal manner by comparing the pattern of actual activity with the patterns of the known fingerprints, and determining abnormal operation exists when the actual pattern is outside the threshold of the fingerprints, and so a fault is likely.

The system has the capability to learn from new information or patterns not previously defined, and can conduct signal-based FDD, and can incorporate such new patterns with a learning tool, such as an expert system, that expands the knowledge database for FDD.

In another embodiment, event conditions are learned by the analysis system.

For example, initially "normal" is defined as a particular value, and "within normal range" is defined as a predetermined difference from the particular value. When the system detects operation outside of normal range, it produces an alarm; if a human then accepts the operation regularly, such as three times, the system adjusts the predetermined difference to a new amount, thereby learning the acceptable behavior of the system.

Use cases will now be discussed with respect to arcing.

Arcing refers to an electrical current in which electrons jump across a gap. Unwanted arcs in electrical circuits can cause fires.

The duration of a single arcing event is generally instantaneous, such as less than one microsecond. The amplitude of the instantaneous spike in an arcing event is characterized by an initial decrease in current followed by an increase in current, as shown in FIG. **2**. It is helpful to distinguish between the spikes in a series of single arcing events, rather than treat a series of spikes as one signal. FIG. **2** shows an instance of a single arcing event.

FIG. **3** shows how an optical sensor detects the arcing event of FIG. **2**. Generally, the optical sensor's digital output corresponds to the spark that a human observes.

Continuous arcing signals represent continuous arcing due to, e.g., intermittent contact or an aging connection, and display a fingerprint detectable using FDD and pattern recognition. Continuous arcing signals are normally below the regular signal amplitude because of the increase in contact resistance, and normally display repeatable patterns useful for diagnosis. FIG. **4** shows a typical continuous arcing signal pattern. The current initially is at a steady-state level. When continuous arcing occurs, the current displays a quick drop in values and jumps up and down with a zigzag pattern. The time duration is about 0.01-2 seconds.

Use Case 1: FDD Based on Fingerprint

FIG. **5** is a chart showing two instances of single arcing, labeled "event**1**" and "event**2**". The abscissa (x-axis) shows time while the ordinate (y-axis) shows current. In this example, sensor **5** is an analog current sensor, whose output, shown in FIG. **5**, is provided to processor **10**, which detects when the signal amplitude has exceeded five times the normal signal amplitude for less than one microsecond, and determines that this is an arcing event because such behavior fits the characteristics of the arcing fingerprint.

After determining that an arcing event exists, in this example, processor **10** continues to monitor the signal. One single arcing event per 5 minutes is defined as acceptable.

Two or more single arcing events per 5 minutes is defined as a possible fault, and processor **10** reports this condition to server **100**. Four or more single arcing events per 5 minutes is defined as a threat, and processor **10** sends a signal to a circuit breaker (not shown) to shut off the current supplied to sensor **5**, and of course, any device that is drawing such current, and processor **10** also reports its automatic shut off to server **100**.

Use Case 2: FDD with Redundancy

FIG. **6** is a chart showing how a digital optical sensor reacts to the signal of FIG. **5**, and generally corresponds to the sparks that humans identify as arcing.

In this example, processor **10** receives the output of an analog current sensor and a digital optical sensor. When the current sensor senses an amplitude of at least five times normal and the optical sensor turns on, then processor **10** concludes that an arcing event has occurred, without concern for the duration of time that the analog signal amplitude exceeds five times the normal. Subsequent processing of processor **10** may be as in use case 1.

Use Case 3: FDD with Change in Sampling Rate

FIG. **7** is a chart showing, as "curveA", the current versus time for an intermittent contact; as "curveB", a sampling rate that is dynamically changed; and as "curveC", the output of a sensor whose sampling rate is dynamically changed.

Let it be assumed that curveA represents an analog signal for a connection that is not secure, i.e., a connection that exhibits an intermittent contact situation. Assume the sampling rate is as shown in curveB, and that curveC represents what is sampled, such as a sensor that turns on when the current is below a threshold value, shown as "threshold" relative to curveA.

Beginning at the left side of curveC, no signal is produced, so the sampling rate stays at a first lower rate. Then, when a signal is produced, the sampling rate is shifted to a second higher rate creating a smaller sampling interval that improves the likelihood of capturing critical information. The sampling rate remains at the higher rate until no signal is produced in five successive sampling intervals, at which time the sampling rate is shifted back to the first lower rate. Five intervals is chosen for ease of illustration; in actuality, the number of intervals is about 50-500 intervals, or an interval amount determined by a FDD algorithm.

Use of a dynamic sampling rate increases the chance that events of interest will be captured, while reducing the data rate during "normal" operation, when no events of interest are occurring, from a fault detection perspective.

A vectorized map for intelligent fault detection and diagnosis (iFDD) and redundancy will now be discussed.

A vectorized map is akin to the Cartesian coordinates with XY axes. Every two sets of data from two sensors can be used to construct a vectorized map to represent the characteristics of faults of a system, in a way similar to that of XY Cartesian coordinates with points on the XY space represented by the coordinates (x, y). This type of vectorized map, after calibration, can provide very useful information for diagnosis. FIG. **8** provides an illustration of how this type of vectorized map can be used.

In FIG. **8**, the current is in the horizontal axis, and the temperature measured at a prescribed location is in the vertical axis. Each measurement has its own threshold value above which a fault can be triggered, as shown in the "red region" area with the arrows indicating the "max. allowable current" and the "temperature threshold". For example, an operating situation illustrated by the point "c" indicates such situation that requires immediate attention due to the presence of fault. When such two signals are plotted on the vectorized map, an intermediate region indicated by the "yellow region" does not, by definition, exceed the threshold of safety; however, the combination of marginally safe operation based on the two sensors can present a safety concern if the operating parameters are maintained at this level for extended period of time. The point "b" illustrates such a condition in this region, which may cause a fault in due time. The "green region" is the region of safe operation, illustrated with a point "a."

Such vectorized map of a pair of sensory data can be applied to include more pairs of data. If there are n such pairs, we effectively will have n ways of looking at the fault under consideration. The information rendered by these n different sources can complement one another and corroborate to render a more reliable diagnosis because of the redundant information.

An iFDD system is adopted, which is capable of exploiting both time-domain and frequency-domain analysis to complement each other. Such system provides redundancy in data analysis and can deliver more precise diagnosis because information on both domains are utilized and corroborated. Such kind of domain redundancy in analysis can be achieved by signal processing algorithms such as wavelet analysis.

Using multiple sensors: redundancy can also be established by using multiple pairs of sensory information. For example, the "Vectorized Map for iFDD" discussed above uses a pair of sensory information. When a different pair of data is employed for FDD, the results can provide "redundancy" to the first diagnosis. The additional diagnosis can confirm the results of the first diagnosis, or to provide additional insights to the first diagnosis. In either case, the two complements each other and can enhance the accuracy of the diagnosis. As a result, the confidence level of FDD is increased.

The "redundancy" referred to above is a result of having more sensors than the minimum set (in this case, one set of data pair) needed for FDD. Such redundancy provides additional benefits in the process of FDD.

Learning will now be discussed.

Event-triggered iFDD depends on the detection of events. A system that is capable of learning and modifying the recognition of events is desirable to intelligently adapt to different operating conditions. This can be done as follows:

- Recognize fingerprint: for example, refrigerator—turning off and on of the compressor. The transition will emit a signal which has its own fingerprint. As an example, when the fingerprint changes suddenly, a fault is likely to be developed in the system. The recognition of such fingerprint and its changes is a reliable way of implementing iFDD. As another example, shown in FIGS. **9**A and **9**B, the reference fingerprint is shown in solid line from the operation without fault. When a fault is developed (in this a leakage in the system), the fingerprint of the signal for the same operation changes and can be used for iFDD. The fingerprint (in solid lines) of reference is the same, but the response from different sources of fault can be different. This can also be utilized as information for FDD. The data shown are from wavelet analysis (for example, cD3 wavelet data).
- Learning of behavior: This is best understood by an example. Let's take the air-conditioner as an example, with a compressor for the heat exchange cycle. When the compressor has been operating normally for a while, a certain reference operating performance is established. At some point, a window in the room was left open which causes the unit to operate harder and turn on for longer period of time, deviating from the nominal operating behavior. If this persists, a warning can be issued to the use to check the surrounding and check if windows/

doors are to be closed to bring the air-conditioner back to normal operations. This learning behavior can save energy by using the aforementioned iFDD algorithm.

A faceplate for an electrical receptacle will now be discussed. The faceplate has a sensor for sensing operation of the device plugged into the electrical receptacle.

FIG. **10** shows an embodiment where the sensor is on the backside of the faceplate. An embodiment where the sensor is on the front side of the faceplate is contemplated, but not shown. As used herein, front side is the side that is visible when the faceplate is installed over an electrical receptacle.

FIG. **10** shows faceplate **200** having apertures **201**, **202**. In a standard receptacle, there are two receptacles, a top receptacle and a bottom receptacle. Aperture **201** surrounds the top receptacle, while aperture **202** surrounds the bottom receptacle. Faceplate **200** also has sensor strips **211**, **212**, **221**, **222**, each of which is formed of a heat conducting material, such as used to dissipate heat from computer chips, described for example in European Patent EP0696630, "Heat conductive material and method for producing same", Feb. 14, 1996, the disclosure of which is hereby incorporated by reference. The width of each sensor strip is such that its inward edge, relative to the aperture is determined so that the inward edge contact a blade of a plug that is plugged into the receptacle.

Sensor strips **211**, **212**, **221**, **222** are constructed similarly. For brevity, only sensor strip **211** is discussed.

Sensor strip **211** is coupled to element **231** that converts its temperature to an electrical signal. Coupling occurs, for example, by connecting element **231** to sensor strip **211** via epoxy. Suitable temperature sensors for element **231** include:

- Analog Devices AD590 2-Terminal IC Temperature Transducer—an integrated circuit that produces an output current proportional to absolute temperature, at temperatures up to 150° C. (316° F.). See www.analog.com.
- Omega.com 44000 Series Thermistor—A thermally sensitive resistor available in two types: negative temperature coefficient (NTC), or positive temperature coefficient (PTC). NTC thermistors have a highly non-linear change in resistance and reduce their resistance with increases in temperature. Epoxy coatings are used for temperatures from −50 to 150° C. (−58 to 316° F.). See www.omega.com.
- Betatherm BetaLinear 36K53A1 thermistor, providing up to 400 times the output of a thermocouple with no need for junction temperature or lead wire compensation, operating at 0 to 100° C.

The output of the temperature sensor element **231** is transmitted, at predetermined intervals, to a controller, such as processor **10**. Specifically, the output of the temperature sensor element is provided to transmitter element **250**, such as the ZM3102N Z-Wave Module, described in the background section of this application. Transmitter **250** obtains power from battery **255**.

Although faceplate **200** has been described in an embodiment wherein the temperature is sensed, other embodiments are contemplated, such as where current or other characteristic is sensed.

FIG. **11** shows a faceplate that senses an operating condition and, upon detection of an exception condition, cuts off power to the electrical receptacle and notifies an external processor. FIG. **11** is similar to FIG. **10**, and only the differences are discussed for brevity.

FIG. **11** shows faceplate **300** that fits over receptacle **380**. Transmitter element **350** also is connected to switch elements **360**, **370**, which are similar to each other; only switch element **370** is discussed in detail. Switch elements **360**, **370** are torus (doughnut) shaped.

Generally, wires can be coupled to receptacles via the side-wire method, in which wire is wrapped under a screw-head, the back-wire method, in which wire is inserted from behind through a hole or slot and clamped under a clamping plate as the screw is tightened, or the push-wire method, in which a wire is simply pushed into a terminal and clamped by a spring-loaded brass member inside the terminal. The push-wire method causes many loose connections, and is not favored for this reason. FIG. **11** shows receptacle **380** adapted for side-wire connection. Screws **385**, **386** are non-conductive screws, such as plastic, rather than the typical metallic screws.

Switch elements **360**, **370** are placed between the contacts on the side of receptacle **380** and the household wiring (not shown), the household wiring being held in place by tightening screws **385**, **386**. Screws **385**, **386** respectively insert through the toroidal centers of switch elements **360**, **370**.

Switch element **370** is has conductive plates **375**, **376**, such as brass or copper alloys, on either side, to ensure conduction between the household wiring and the side of receptacle **380**, respectively. Plates **375**, **376** are connected to wires **377**, **373**. Movable wire **372** is controlled by control wire **371** to connect between wire **377** and either wire **373** or ground **374**.

During normal operation, movable wire **372** is connected between wire **377** and wire **373**, so that power flows through receptacle **380**. When transmitter element **350** detects that the sensed temperature exceeds a predetermined temperature, transmitter element **250** sends a signal along control wire **371** to switch movable wire **372** to ground **374**, thus cutting off power to receptacle **380**. In other embodiments, controller **10** commands transmitter element **350** to control switching elements **360**, **370** to cut off power to receptacle **380**.

FIG. **12**A shows a back view current tap **400**. FIG. **12**B shows a side view of current tap **400**. Generally, current tap **400** has a top pair of prongs **403**, **405**, top ground prong **407**, a bottom pair of prongs **404**, **406**, and bottom ground prong **408**, for respectively plugging into a household outlet. Current tap **400** also provides receptacles **470**, **480**, **490**, each having two slots for the prongs of a device plug, and also each having an opening for a ground prong of a device plug.

Top prongs **403**, **405** provide power to receptacles **470**, **480**, **490**. Prongs **403**, **405** are in conductive contact with elements **411**, **412**, that function similarly to elements **211**, **212** discussed above with regard to faceplate **200**.

Bottom prongs **404**, **406** provide power to transformer **460**.

During normal operation, transmitter element **450** derives power through bottom prongs **404**, **406**. However, when an exception condition occurs, or when commanded by processor **10**, transmitter element **450** switches to battery **450** for its power.

In other embodiments, sensors are provided for each of receptacles **470**, **480**, **490**.

FIG. **13** is a schematic of circuit **500** according to the present invention, shown as a receptacle. In another embodiment, the circuit is a plug-in device, for retrofitting an existing outlet, lacking sensors **550**, **560**.

Line current is supplied to load **590** via switch **510** controlled by controller **511**.

Temperature sensor **520**, such as a thermocouple (e.g., Omega part 5TC-TT-K-36-36) or thermistor (e.g., General Electric part RL503-27.53K-120-MS), is located next to the screw (not shown) or other fastener for the line wire, as this location tends to become hot in a receptacle. Another hot spot is the blades of a plug. In a plug-in retrofit device, sensor **520** is located near the blade that is plugged into the plug-in retrofit device. Sensor **520** produces a sensed temperature signal, and supplies the sensed temperature signal to sample

and hold data acquisition (SHDAC) element **521** (e.g., National Semiconductor part ADC1615626) that serves to latch (preserve in time) the sensed temperature signal, so that its time reference can be synchronized with other sensed signals. SHDAC element **521** supplies the latched sensed temperature signal to analog-to-digital converter (ADC) **522** that operates to convert the analog sensed temperature signal to digital data, and supplies the digital sensed temperature signal to microprocessor **570**.

Light sensor **530**, such as a photodiode (e.g., Advanced Photonix Inc. part PDB-C158F) or infrared camera, is located near the screw (not shown) or other fastener for the line wire. Sensor **530** produces a sensed light signal, and supplies the sensed light signal to SHDAC **531** that operates in similar manner as SHDAC **521**. ADC **532** operates in similar manner as ADC **522** to supply a digitized sensed light signal to microprocessor **570**.

Audio sensor **540**, such as a microphone (e.g., Knowles Acoustics part MD9745APA-1), is located at a convenient place in or on the receptacle. Sensor **540** produces a sensed audio signal, and supplies the sensed audio signal to SHDAC **541** that operates in similar manner as SHDAC **521**. ADC **542** operates in similar manner as ADC **522** to supply a digitized sensed audio signal to microprocessor **570**.

Current sensor **550** is a Hall-effect current sensor (e.g., Functional Devices Inc. part RIBX420 or Eaton Cutler-Hammer part EAC1420SP) and senses the line current supplied to load **590**. Sensor **550** produces a sensed current signal, and supplies the sensed current signal to SHDAC **551** that operates in similar manner as SHDAC **521**. ADC **552** operates in similar manner as ADC **522** to supply a digitized sensed current signal to microprocessor **570**.

Optional ground fault sensor **560** produces a ground fault trip signal, and supplies the ground fault trip signal to SHDAC **561** that operates in similar manner as SHDAC **521**. ADC **562** operates in similar manner as ADC **522** to supply a digitized ground fault trip signal value to microprocessor **570**.

Microprocessor **570** is a general purpose microprocessor programmed according to the present invention, and includes suitable memory (not shown). Microprocessor **570** receives the digitized values from ADCs **522**, **532**, **542**, **552**, **562**, and generates a control signal for controller **511** to interrupt the line current, generates control signal **581** for status light(s) **580**, which may be one or more light emitting diodes (LEDs) or other suitable device, generates control signal **586** for siren **585**, which may be a speaker or other device emitting an audible signal, and generates a communication signal for wireless communication interface **505** that communicates with controller **20** of FIG. **1**. Microprocessor **570** also receives communication signals via communication interface **505** from controller **20**. Microprocessor **570** also generates sampling frequency control signals fT, fL, fA, fi and respectively supplies these control signals to sensors **520**, **530**, **540**, **550**.

FIG. **14** is a flowchart for the operation of microprocessor **570** of FIG. **13**.

At step **600**, microprocessor **570** is turned on, such as by receiving power, or is reset by a reset button (not shown) in the receptacle or plug-in retrofit device containing circuit **500**.

Microprocessor **570** then simultaneously executes five processes **680**-**684** respectively corresponding to sensors **520**, **530**, **540**, **550**, **560**. Processes **680**-**684** supply problem signals to fault analysis step **650** that determines whether to take one or more of a variety of actions, such as interrupting the line current, activating/de-activating status light(s) **580**, activating/de-activating siren **585**, sending a message to controller **20** and so on.

Process **680** will now be described. Process **680** includes steps **605**, **610**, **615**, **620**, **625**, **630**, **635**, **640**A-**640**C.

At step **605**, microprocessor **570** sets sampling frequency control signal fT to a first value fT**1**, such as 100 Hz, and supplies control signal fT to temperature sensor **520**.

At step **610**, microprocessor **570** receives values from ADC **522** at the rate determined by signal fT, in this example, 100 samples per second, and stores them in an internal circular buffer or storage such that only the most recent values are stored. For example, if the buffer size is 1000 samples, then the most recent 10 seconds of sensed values are stored.

At step **615**, which occurs periodically such as every 30 seconds, microprocessor **570** analyzes the stored values to produce an analysis result.

The analysis at step **615** analyzes the sensed temperature signals in view of the type of problem being detected to produce a confidence estimate of the problem. For example, when the problem being detected is serial arcing, the temperature in the area surrounding the arcing characteristically rises in a slanted sawtooth curve, as shown in FIG. **15**.

Serial arcing is typically found in outlets which have aging wire connections and/or degraded joints. The serial arcing is caused mainly by intermittent contact due to rusted wire and/or rusted screw and/or degraded junction which causes accelerated failure of connection. Once serial arcing begins, the connection continues to degrade until it becomes hazardous because of the resulting sharp temperature rise when a load is applied to the outlet. The temperature can rise to over 200° C. is 10 seconds for a continuous serial arcing connection.

The problem analysis at step **615** tries to detect a rising temperature in the sampled data, as follows.

Let

T**0** be the oldest data sample in the circular buffer,

Tn be the most recent data sample in the circular buffer, and

Tavg be the average value of all samples in the circular buffer.

If

$$(Tn-T0>Tavg*0.1)$$

then the samples probably are characteristic of a rising temperature and hence serial arcing may be occurring. Other specific tests or values will be apparent to those of ordinary skill in the art; an important feature of the test is that it is to detect the behavior expected to be found when the problem occurs.

At step **620**, microprocessor **570** determines whether the analysis result produced at step **615** indicates there is a problem. If not, processing returns to step **605**. If there is a problem, processing proceeds to step **625**.

At step **625**, which occurs if a fault is determined at step **620** or can also occur if problem signal BB is received, microprocessor **570** sets sampling frequency control signal fT to a second value fT**2** that is higher than the first value fT**1**, such as fT**2**=1000 Hz, and supplies control signal fT to temperature sensor **520**. Microprocessor **570** also generates problem signal BB and supplies it to steps **626**, **627**, **628** of processes **681**, **682**, **683**.

It will be appreciated that, in this manner, when any of sensors **520**, **530**, **540**, **550** generates data indicating a possible fault, all of the sensors then begin to sample at a higher frequency, enabling analysis in a more time-granular fashion. That is, when things appear normal, a first lower sampling rate is used to reduce power consumption, while when a possible fault occurs, a second higher sampling rate is used despite the higher power consumption to enable detection of

transient faults. In embodiments where power consumption is not a concern, the second higher sampling rate may be used constantly.

At step **630**, microprocessor **570** receives data from ADC **522** at the higher rate, in this example, 1000 samples per second, and stores them its internal circular buffer or storage such that only the most recent values are stored. For example, if the buffer size is 1000 samples, then the most recent 1000 milliseconds of sensed data are stored.

At step **635**, which occurs periodically such as every 500 milliseconds or every 100 milliseconds or every 2 seconds, microprocessor **570** analyzes the stored values to produce an analysis result. The analysis at step **635** is similar to the analysis at step **615** but occurs with more temporal granularity due to the higher sampling rate, and instead of a binary result (problem or normal), the result is a confidence estimate of whether a fault exists. Let **771** be the CONFIDENCE value for the temperature samples. An example analysis is:

If (Tn>2T**0**) then (η_1=1.00)
else if (Tavg<32° F.) then (η_1=0)
else if (32° F.<Tavg<150° F.) then (η_1=(Tn−T**0**)/T**0**)
else (η_1=0.97)

This analysis says that if the most recent temperature sample is twice the initial temperature sample, then there is definitely a problem (CONFIDENCE=100%). If the average temperature of the temperature samples in the circular buffer is at least 150° F., then the CONFIDENCE that there is a problem is 97%. While the average temperature is between 32° F. and 150° F., then the CONFIDENCE is the normalized temperature difference between the oldest and newest samples. If the average temperature is under 32° F., then there is definitely not a fault.

At step **640**A, microprocessor **570** determines whether the analysis result produced at step **635** indicates there is a fault. If not, processing returns to step **605**. If there is a fault, processing proceeds to step **650**. Continuing with the above example, if η_1 is at least 0.5, then there is a problem.

It will be appreciated that the sensed temperature data can be analyzed in different ways to detect different types of fault s. As described above, the fault of serial arcing is considered. Other faults, such as appliance malfunctioning (the appliance is load **590**) or fire hazard, may be considered by analyzing the sensed temperature values in different manner. In some embodiments, microprocessor **570** conducts multiple analyses on the sensed data, and thus has steps **640**B, **640**C and so on corresponding to the different types of fault analyses. In this embodiment, if one or more fault s are detected, processing proceeds to step **650**, that is, only if no fault s are detected does processing return to step **605**.

Process **681** includes steps **606**, **611**, **616**, **621**, **626**, **631**, **636**, **641**A-**641**C. Process **681** is similar to process **680**, and for brevity, only differences will be discussed. When serial arcing occurs, the curve of light generated is similar to the curve of current, discussed below, and the light samples are analyzed similarly.

Process **682** includes steps **607**, **612**, **617**, **622**, **627**, **632**, **637**, **642**A-**642**C. Process **682** is similar to process **680**, and for brevity, only differences will be discussed. When serial arcing occurs, the curve of sound generated is similar to the curve of current, discussed below.

Process **683** includes steps **608**, **613**, **618**, **623**, **628**, **633**, **638**, **643**A-**643**C. Process **683** is similar to process **680**, and for brevity, only differences will be discussed.

FIG. **16** shows typical current vs. time curves for serial arcing and for normal current without arcing. The normal non-arcing current is basically flat with high frequency noise. In contrast, the serial arcing curve has a pronounced W-shaped period.

FIG. **17** shows exemplary Fast Fourier Transform (FFT) spectra of the current vs. frequency curves for normal operation and serial arcing. The normal non-arcing FFT spectrum has a lot of energy in low frequencies and asymptotically decreasing energy in higher frequencies, with pronounced spikes at 60 Hz and 180 Hz. The serial arcing curve is similar but also has pronounced spikes at 300 Hz and 420 Hz. In different configurations, the spikes may occur at different frequencies, but there will be additional spikes in the arcing spectrum relative to the normal operation spectrum.

At step **618**, a test corresponding to FIG. **16** is used. For the stored current samples in the circular buffer, the following values are determined:

Imin=the minimum value of the current samples
Imax=the maximum value of the current samples
Iavg=the average value of the current samples

The test is:

If (Imin<0.95*Iavg) then serial arcing exists, else no serial arcing exists.

At step **638**, a more elaborate version of a test corresponding to FIG. **16** is used. In other embodiments, other tests are used. Choose an upper bound βu, such as βu=0.3, and a lower bound βl, such as βl=0.03. The confidence value for the current samples is η_4, computed as:

$$\eta_4 = \left[\frac{(I\max - Iavg)/Iavg - \beta l}{(\beta u - \beta l)}\right] * 0.5 + \left[\frac{(Iavg - I\min)/Iavg - \beta l}{(\beta u - \beta l)}\right] * 0.5$$

In another embodiment, at step **618**, a test corresponding to FIG. **17** is used. The stored current samples in the circular buffer are subjected to a Fast Fourier Transform.

Let v=the magnitude of the frequency spectrum at an identified arcing frequency, such as 300 Hz.

Let Amax=a predetermined maximum value for the magnitude of the frequency spectrum at the identified arcing frequency.

Let Amin=a predetermined minimum value for the magnitude of the frequency spectrum at the identified arcing frequency.

The specific values of Amax and Amin are determined by the characteristics of the signals and arcing for specific loads and/or outlets.

The test is:

If (v>Amin) then serial arcing exists, else no serial arcing exists.

In another embodiment, at step **638**, a more elaborate version of a test corresponding to FIG. **17** is used. The confidence value of a fault based on the current samples is η_4, computed as:

$$\eta_4 = \begin{cases} 0.5 * [(v - A\min)/(A\max - A\min)] + 0.4, & A\min < v < A\max \\ 0.95, & v \geq A\max \end{cases}$$

Process **684** includes step **624**, wherein a ground fault trip signal from ground fault sensor **560**, as digitized, is simply passed to step **650**.

At step **650**, triggered by arrival of a problem signal and then occurring for one or more subsequent periods to see if the problem has cleared, microprocessor **570** performs redundant fault analysis by combining the CONFIDENCE values of the

problem signals, if any, from processes **680**-**684**. A separate analysis is performed for each type of problem being considered. Additionally, if the ground fault trip signal indicates a ground fault, then the fault analysis immediately indicates a ground fault so that the current is interrupted to load **590**.

In one embodiment, the fault confidence signals are combined as follows:

$$\eta_{fault} = 1 - \prod_{i=1}^{n} (1 - \eta_i)$$

In this example, n=4 since the results of four sensors are provided at step **650**.

η_1 corresponds to the CONFIDENCE of the sensed temperature from process **680**.

η_2 corresponds to the CONFIDENCE of the sensed light from process **681**.

η_3 corresponds to the CONFIDENCE of the sensed audio from process **682**.

η_4 corresponds to the CONFIDENCE of the sensed current from process **683**.

The confidence values η_1, η_2, η_3, η_4 are between 0.0 and 1.0.

In another embodiment, the problem signals are weighted; for instance, the sensed current may be deemed to be a better indicator than the sensed light, so the sensed current influences the outcome of the redundant fault analysis more than the sensed light.

For example, assume confidence values η_1=0.62, η_2=0.71, and η_4=0.82 are delivered to step **650**; in this example, there does not seem to be an audio problem perhaps because of loud ambient noise so no value for η_3 is delivered to step **650**, i.e., η_3=0. The values are combined as:

$$\begin{aligned}\eta_{fault} &= 1 - (1 - 0.62) * (1 - 0.71) * (1 - 0) * (1 - 0.82) \\ &= 1 - (.38) * (.29) * 1 * (.18) \\ &= 0.98\end{aligned}$$

Thus, using three samples increases the overall level of confidence dramatically. That is, a fault that manifests simultaneously in multiple domains, even if it is not so serious in each domain, gives rise to strong confidence that a problem truly exists. It is preferred to use at least three domains, that is, redundancy in two domains.

At step **655**A, corresponding to the problem of serial arcing, microprocessor **570** determines what action, if any, it should take. If no action is to occur, processing continues at step **670**. Otherwise, at step **660**A, the action is taken. For example, microprocessor **570** may be programmed to with the following rule:

If (η_{fault}>0.98) then (set signal **511** to open switch **510** and make status light **580** red)

else if (0.95<η_{fault}<0.98) then (make status light **580** blinking and red)

else if (0.90<η_{fault}<0.95) then (make status light **580** red)

else if (0.70<η_{fault}<0.90) then (send an alert message to controller **20**)

Other rules for actions will be apparent to those of ordinary skill.

At step **655**B, corresponding to another fault such as appliance malfunction, microprocessor **570** determines what action, if any, it should take. If no action is to occur, processing continues at step **670**. Otherwise, at step **660**B, the action is taken. For example, microprocessor **570** may be programmed to with the following rule:

If (η_{fault}>0.95) then (activate siren **585**)

else if (0.80<η_{fault}<0.95) then (send an alert message to controller **20**)

Other actions will be apparent to those of ordinary skill. For example, if load **590** is an air-conditioner drawing too much current, the action may be to regulate the voltage or current and send an alert message to controller **20** to calibrate the air-conditioner as it is running inefficiently.

At step **655**C, corresponding to another fault such as fire hazard, microprocessor **570** determines what action, if any, it should take. If no action is to occur, processing continues at step **670**. Otherwise, at step **660**C, the action is taken.

At step **670**, if no faults are detected, then normality signal AA is generated and provided to processes **680**-**683** so that all processes return to a lower sampling rate.

Although an illustrative embodiment of the present invention, and various modifications thereof, have been described in detail herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to this precise embodiment and the described modifications, and that various changes and further modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention as defined in the appended claims.

What is claimed is:

1. A method of performing problem detection/prediction, diagnosis, and resolution within an electrical provision device while minimizing power consumption, said method comprising:

using a microprocessor with a memory to simultaneously set a low, power-saving sampling frequency for one or more sensor types,

using said one or more sensors to sense one or more respective operating characteristics of the electrical current provision device at said low sampling frequency,

storing recent readings of each of said one or more sensors in a buffer portion of said memory,

periodically analyzing said readings in said buffer using said microprocessor, by comparing said readings in said buffer with an accepted normal range for each of said respective sensor readings, wherein each of said readings being within said range comprises normal operation and wherein at least one of said sensor readings exceeding said range comprises abnormal operation,

instituting an event-triggered sampling frequency for each of said one or more sensors when said at least one sensor reading in said buffer exceeds said accepted normal range, said event-triggering sampling frequency being at a higher sampling frequency than said low, power-saving sampling frequency,

storing said one or more sensor readings at said event-triggered sampling frequency in said buffer portion of said memory,

frequently analyzing said event-triggered readings in said buffer, said frequent analyzing comprising determining a confidence value, for said at least one sensor, indicating an amount of confidence that a fault exists, said frequent analyzing of said event triggered sensor readings occurring at a frequency being greater than said periodic analyzing of said sensor readings,

performing a redundant fault analysis, when said at least one abnormal sensor reading persists for two or more occurrences of said frequent analyzing of said event-

triggered readings, said redundant fault analysis comprising a combined confidence value for at least two sensors,

taking a control action to resolve said existing fault, when said combined confidence value exceeds a predetermined threshold, by said microprocessor generating a control signal that is received by a controller, thereby causing said controller to command said control action, and

generating a normality signal if said combined confidence value does not exceed said threshold, or if said abnormal sensor reading clears before said two or more occurrences of said frequent analyzing, said normality signal causing return to said low, power-saving sampling frequency.

2. The method of claim **1**, wherein each of said one or more operating characteristics is one of temperature, humidity, light, sound, vibration, voltage, power, and line current.

3. The method of claim **1**, wherein said fault is one of serial arcing, appliance malfunction, and fire hazard.

4. The method of claim **1**, wherein said control action comprises one or more of

sending, by said processor, a control signal for commanded control action by said controller in response to instructions entered locally on an input device or instructions received remotely over the internet; and

sending, by said processor, a control signal for a predetermined control action, said predetermined control action comprising one or more of:

(a) preventing line current from flowing in the electrical current provision device,

(b) activating a status light,

(c) activating a sound generator, and

(d) sending a message to a controller.

5. The method of claim **1**, wherein said at least two sensors have confidence values of $\eta_1, \ldots, \eta_n$, and wherein said combined confidence value, η_{fault}, is given by the equation:

$$\eta_{fault} = 1 - \prod_{i=1}^{n} (1 - \eta_i).$$

6. The method of claim **5**, wherein when said at least two sensors comprises two sensors, η_1 corresponds to a confidence value of a fault from a temperature reading sensed from a first sensor, and η_2 corresponds to a confidence value of a fault from a light reading sensed from a second sensor.

7. The method of claim **6** wherein when said at least two sensors comprises a third sensor, η_3, corresponds to a confidence value of a fault from an audio reading sensed from said third sensor.

8. The method of claim **7**, wherein when said at least two sensors comprises a fourth sensor, η_4 corresponds to a confidence value of a fault from a current reading sensed from said fourth sensor.

9. The method of claim **4** further comprising instructing said processor to ignore said at least one sensor reading in said buffer that exceeds said accepted normal range; and adjusting said accepted normal range to be a new normal range that include said abnormal sensor reading, when regularly commanded to ignore said abnormal sensor reading.

10. The method of claim **9**, wherein commanding said processor to ignore said abnormal sensor reading regularly comprises commanding said processor to ignore said abnormal sensor reading at least three times.

11. The method of claim **1**, wherein said low, power-saving sampling frequency comprises sampling at approximately 100 Hz; and wherein said higher event-triggered sampling frequency comprises sampling at approximately 1000 Hz.

12. The method of claim **11**, wherein said periodically analyzing comprises analyzing approximately every 10-30 seconds; and wherein said frequently analyzing comprises analyzing in the range of approximately every 500 milliseconds to approximately every 2 seconds.

13. The method of claim **1**, wherein said one or more sensor types comprise one or more of a photodiode or camera for sensing light; a 2-axis accelerometer for sensing vibrations; a microphone for sensing sound; a thermocouple or infrared imager for sensing temperature; a Hall-effect sensor for sensing current.

14. The method of claim **1** wherein said storing recent readings in said buffer portion of said memory comprises storing said one or more sensor readings until completing said periodic analyzing using said readings.

15. The method of claim **14** wherein said periodic analyzing of said recent sensor readings for serial arcing comprises:

determining a minimum current value, I_{min}, of said recent current sensor readings;

determining a maximum current value, I_{max}, of said recent current sensor readings determining an average current value, I_{avg} of said recent current sensor readings; and

wherein said at least one sensor reading exceeding said accepted normal range is where $I_{min} < 0.95(I_{avg})$.

16. The method of claim **15**, wherein said confidence value of said frequent analyzing of said event-triggered current readings comprises:

$$\eta = \left[\frac{(lmax - lavg)/lavg - \beta l}{(\beta u - \beta l)}\right] * 0.5 + \left[\frac{(lavg - lmin)/lavg - \beta l}{(\beta u - \beta l)}\right] * 0.5$$

where β_u is an upper bound, and β_l is a lower bound, and wherein β_u is approximately 0.3 and β_l is approximately 0.03.

17. A method of performing intelligent problem detection/prediction, diagnosis, and resolution within an electrical current provision device, said method comprising:

using one or more sensors to detect a possible problem, each of said one or more sensors sensing an operating characteristic of one or more components of said electrical current provision device at a first sampling rate, said first rate being a power-saving sampling rate;

comparing a present sensor reading of each of said one or more sensors with an acceptable range for said respective sensor reading;

wherein when said present sensor reading is within said acceptable range, storing said present sensor reading in a controller;

wherein when at least one of said present sensor readings is outside said acceptable range indicating detection of a possible problem, instituting an event-triggered sampling rate for said one or more sensors, said event-triggering sampling rate being at a higher frequency than said first sampling rate,

analyzing said event triggered readings to produce a confidence estimate to diagnose whether the problem is a fault,

taking a control action, by a processor, to resolve said fault when said confidence estimate exceeds a predetermined threshold, and

returning said one or more sensors to sensing at said first sampling rate when said at least one sensor reading returns within said acceptable range.

18. The method of claim **17**, wherein said operating characteristic is one of: temperature readings, humidity readings, voltage readings, power readings, image readings, vibration readings, and acoustic readings.

19. The method of claim **18**, wherein said fault is one of serial arcing, excessive energy consumption, appliance malfunction, and fire hazard.

20. The method of claim **19**, wherein two or more sensors are used for sensing two or more operating characteristics; and wherein when at least one of said two or more operating characteristics sampled at said first sampling rate detects a possible problem, generating two or more confidence estimates using said event-triggered sampling rate, said two or more confidence estimates being $\eta_1, \ldots, \eta_n$.

21. The method of claim **20** further comprising improving an overall level of confidence of said fault by checking for abnormality in multiple domains by combining said two or more confidence estimates to generate a combined confidence estimate, η_{fault}, said combined confidence estimate is given by the equation:

$$\eta_{fault} = 1 - \prod_{i=1}^{n} (1 - \eta_i).$$

22. The method of claim **21** further comprising one or more of:

(a) taking, by said processor, a commanded control action by responding to instructions entered locally on an input device or received remotely over the interne; and

(b) taking, by said processor, a predetermined control action, said predetermined control action comprising one or more of:

(i) preventing line current from flowing in the electrical current provision device,

(ii) activating a status light,

(iii) activating a sound generator to generate an audible alarm, and

(iv) sending a message to a personal computer or cell phone.

23. The method of claim **22** further comprising commanding said processor to ignore said present reading being outside said acceptable range; and adjusting said acceptable range to a new range to include said present reading, when regularly commanded to ignore said present reading.

24. The method of claim **23** wherein commanding said processor to ignore said present reading regularly comprises commanding said processor to ignore said present reading at least three times.

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